Extracting Anisotropic Plasticity from a Single Heterogeneous Test Using Full-Field Measurements

B. Starman[1], A. Maček[1], S. Coppieters[2], P. Lava[3], F. Pierron[3] and M. Halilovič[1a]

[1]University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia,
[2]KU Leuven, Dep. of Materials Engineering, Ghent Technology Campus, Ghent, Belgium
[3]MatchID, Ghent, Belgium

[a]miroslav.halilovic@fs.uni-lj.si

Abstract. The identification of anisotropic plasticity models for sheet metals typically relies on multiple mechanical tests, each probing a limited range of stress states, which makes the process experimentally demanding and prone to inconsistencies. This work explores the use of a single heterogeneous test, based on a purpose-designed cruciform specimen, combined with full-field measurements to enable parameter identification within a unified framework. The approach leverages full-field strain data and inverse modelling via a direct-levelled finite element model updating (FEMU) strategy. Particular attention is given to the role of model parametrisation, showing that physically interpretable formulations significantly improve parameter identifiability compared to conventional representations. Virtual experiments demonstrate that the proposed setup provides sufficient information to robustly identify anisotropic plasticity models, reducing reliance on multiple standard tests and highlighting the potential of heterogeneous testing as a practical route towards single-test characterisation of sheet metal anisotropy.

Introduction

The calibration of anisotropic plasticity models for sheet metals commonly relies on multiple mechanical tests, such as uniaxial tension, biaxial loading and shear, each probing a limited portion of the stress space [1]. While well established, this approach is experimentally demanding and often leads to inconsistencies due to test-to-test variability and limited information content within individual experiments. Full-field measurement techniques, such as digital image correlation, enable detailed observation of heterogeneous deformation fields and offer new opportunities for parameter identification from a single experiment [2].

In this work, a single heterogeneous test based on a purpose-designed cruciform specimen is employed in combination with full-field measurements to enable parameter identification within a unified framework. The methodology integrates full-field data with inverse modelling using a direct-levelled finite element model updating (FEMU) approach [3,4,5]. Particular emphasis is placed on the role of model parametrisation, demonstrating that physically interpretable formulations significantly improve parameter identifiability compared to conventional representations. The proposed approach is assessed through virtual experiments, highlighting its potential for robust single-test characterisation of anisotropic plasticity.

Methodology

The proposed approach is based on a heterogeneous biaxial test using a purpose-designed cruciform specimen, which promotes the development of spatially varying stress and strain states within a single experiment. The specimen geometry is tailored to activate a wide range of stress states, including near-uniaxial and biaxial state dominant regions (Fig. 1a), enabling rich full-field strain data to be obtained from a single test. Parameter identification is performed by combining full-field measurements with inverse modelling through a finite element model updating (FEMU) framework (Fig. 1b). A direct-levelling strategy is employed, in which FEM-computed displacement fields are interpolated onto the measurement grid and processed using the same strain reconstruction procedure as applied to the experimental data. The anisotropic plasticity response is described using the YLD2000-2d model, considered in different parametrisation forms. Particular attention is given to the influence of model parametrisation on the identifiability of material parameters. A physically interpretable formulation is adopted and compared to the conventional parameter representation, enabling a systematic assessment of parameter sensitivity and correlation within the inverse identification procedure.

Results

The identifiability of the anisotropic plasticity parameters was first assessed by analysing the sensitivity and correlation of the parameters within the inverse identification procedure. The results reveal that the conventional parameter representation leads to strong correlations and poor conditioning, limiting the robustness of the identification (Fig. 2a). In contrast, the physically interpretable parametrisation significantly improves parameter identifiability, resulting in a well-posed inverse problem (Fig. 2b).

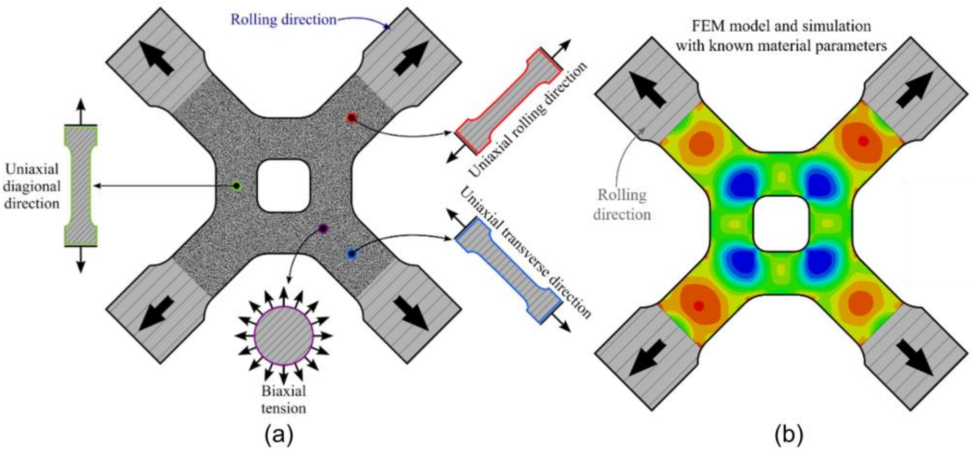

Figure 1. Heterogeneous specimen design combining 3 uniaxial tensile and biaxial test into one design: (a) dominant stress states in individual ligaments; (b) equivalent plastic strain evolution.

The performance of the proposed approach was further evaluated through digital virtual testing. The identified parameters were used to predict the full-field response under the same heterogeneous loading conditions, showing good agreement between reference and reconstructed strain fields. The results demonstrate that the combination of a heterogeneous test, full-field measurements and an appropriate parametrisation enables robust identification of anisotropic plasticity models from a single experiment.

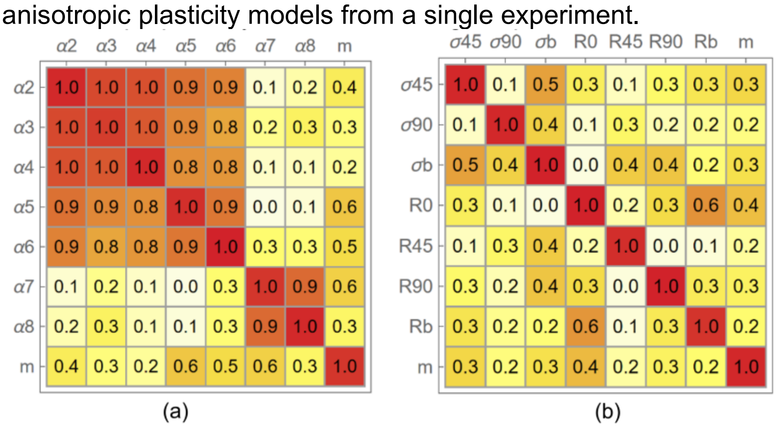

Figure 2. Correlation matrix showing interaction between (a) alpha-based and (b) physically interpretable Yld2000-2d formulation.

Conclusion

This work demonstrates the potential of combining a heterogeneous cruciform test with full-field measurements and inverse modelling for the identification of anisotropic plasticity models from a single experiment. The results highlight the critical role of model parametrisation, showing that physically interpretable formulations of the YLD2000-2d model significantly improve parameter identifiability and robustness. The proposed approach reduces the reliance on multiple standard tests while preserving a high level of accuracy in the reconstructed response. The experimental implementation is currently underway using an in-house developed biaxial testing system, with the ultimate goal of extending the framework towards virtual fields method (VFM)-based identification. These findings support the use of heterogeneous testing and full-field data as a viable alternative for the characterisation of sheet metal anisotropy.

Acknowledgement. The authors acknowledge financial support from ARIS for Research Programme P2-0263, and support from the Flanders Agency for Innovation & Entrepreneurship (No. HBC.2024.0807).

References

[1] Maček A, Starman B, Mole N, Halilovič M. *Calibration of Advanced Yield Criteria Using Uniaxial and Heterogeneous Tensile Test Data*. Metals (2020) 10:542.

[2] Pierron F, Grédiac M. *Towards Material Testing 2.0. A review of test design for identification of constitutive parameters from full-field measurements*. Strain (2020) n/a:e12370.

[3] Chen B, Starman B, Halilovič M, Berglund LA, Coppieters S. *Finite Element Model Updating for Material Model Calibration: A Review and Guide to Practice*. Arch Comput Methods Eng (2025) 32:2035–112.

[4] Lava P, Jones EMC, Wittevrongel L, Pierron F. *Validation of finite-element models using full-field experimental data: Levelling finite-element analysis data through a digital image correlation engine*. Strain (2020) 56:e12350.

[5] Coppieters S, Hakoyama T, Eyckens P, Nakano H, Van Bael A, Debruyne D, et al. *On the synergy between physical and virtual sheet metal testing: calibration of anisotropic yield functions using a microstructure-based plasticity model*. Int J Mater Form (2019) 12:741–59.